International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-5; Sep-Oct, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

The Impact of *Aethina tumida* Infestation on *Apis mellifera* Colonies: A Review of Control Measures and Future Prospects

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Received: 02 Sep 2025; Received in revised form: 02 Oct 2025; Accepted: 05 Oct 2025; Available online: 13 Oct 2025

***Abstract*— *The small hive beetle (Aethina tumida Murray) is a significant invasive pest affecting Apis mellifera colonies worldwide, leading to severe consequences for beekeeping and agricultural pollination. This review examines A. tumida biology, its economic impact, and current control measures. While chemical pesticides such as Coumaphos and Permethrin have been widely used, concerns over toxicity, environmental contamination, and resistance development highlight the need for sustainable alternatives. Emerging strategies provide eco-friendly solutions, including biological control agents (Beauveria bassiana, Steinernema spp.), botanical pesticides (Jatropha curcas, neem oil), and mechanical trapping. Integrated Pest Management (IPM) combines multiple approaches, is increasingly seen as an effective strategy for long-term A. tumida management. However, research gaps persist in optimizing field applicability, standardizing botanical pesticide formulations, and assessing economic feasibility. This review underscores the need for regulatory frameworks, beekeeper adoption of sustainable practices, and large-scale studies to validate these emerging approaches. It also explores prospects, including biotechnological innovations, genetic engineering, artificial intelligence-driven monitoring, and regulatory improvements, to ensure sustainable beekeeping practices.*

Keywords*— *Aethina tumida, Apis mellifera,, , biological control, botanical pesticides, Integrated Pest Management

I. INTRODUCTION

1.1 Importance of Honeybees in Agriculture

Honeybees (*Apis mellifera*) play an essential role in global agriculture, primarily as pollinators supporting biodiversity and food security [1]. According to Hristov *et al.* (2020) and Malav *et al.* (2022), approximately 75% of the world's flowering plants and 35% of crops depend on animal pollination, with honeybees being among the most efficient pollinators. The ability of honeybees to forage over long distances, adapt to diverse environments, and maintain large colony sizes makes them indispensable to both natural ecosystems and managed agricultural systems [2,3,4].

The economic value of honeybee pollination services is estimated between $235 billion and $577 billion annually, demonstrating their critical role in sustaining food production [5,6,7]. Crops such as almonds, apples, blueberries, cucumbers, and coffee are highly dependent on honeybee pollination for improved yields and quality [8,9,10].

Beyond pollination, honeybees also support the global beekeeping industry, generating billions of dollars in revenue through honey, beeswax, propolis, and royal jelly production [11,12,13]. The global honey market is valued at over $8 billion, with China, the United States, Turkey, and Argentina being the leading producers [14,15,16]. Beeswax is widely used in cosmetics, pharmaceuticals, and candle-making, while propolis and royal jelly have gained attention for their antimicrobial and immune-boosting properties [17]. Beekeeping also serves as a primary livelihood for millions of people, particularly in rural areas, where honey production supports economic stability [18,19].

Despite their importance, honeybee populations are in decline due to multiple stressors that threaten both wild and managed colonies [20,21]. Habitat destruction caused by urbanization and deforestation has reduced floral resources, leading to nutritional deficiencies and weakened immune responses [22,23,24,25]. Climate change further exacerbates these challenges by altering flowering periods, disrupting foraging behavior, and increasing the frequency of extreme weather events [26,27,28]. Pesticide exposure, particularly from neonicotinoids, has been linked to navigation impairment, reduced foraging efficiency, and decreased reproductive success, contributing to large-scale colony losses [29,30,31]. Additionally, emerging pathogens and parasites, such as Varroa destructor, Nosema spp., and viral infections, have increased honeybee mortality rates globally [32,33,34]. Among these threats, the small hive beetle [35,36].

II. OVERVIEW

2.1 Overview of Aethina tumida Lifecycle, Behavior, and Economic Impact

The small hive beetle [37]. The lifecycle begins when female beetles lay clusters of eggs inside beehives, typically within cracks or near pollen and brood cells [38]. The eggs hatch within 2-4 days, giving rise to larvae that immediately begin feeding on hive resources, including honey, pollen, and bee brood [38,39]. The larval stage lasts approximately 10-14 days, during which larvae grow and create extensive tunneling damage in honeycombs, causing honey to ferment and become unpalatable [40]. Once mature, the larvae exit the hive and burrow into the soil surrounding the hive to pupate, undergoing metamorphosis over a period of 3-6 weeks before emerging as adults [41]. Adult beetles then seek out new hives to invade, perpetuating the infestation cycle [42].

Behaviorally, A. tumida exhibits highly opportunistic behavior, often targeting weakened or stressed bee colonies for invasion [43]. Adult beetles possess a keen ability to detect and locate beehives from considerable distances by responding to olfactory signals emitted by bee pheromones and volatile compounds produced within the hive [44]. Once inside, they employ adaptive survival strategies, including mimicry, which enables them to avoid detection and aggression from worker bees [45]. Additionally, these beetles demonstrate exceptional mobility and resilience, allowing them to persist without food for extended periods, particularly in cooler environments where their metabolic rates slow down [46]. This adaptability contributes to their success as persistent hive pests, making them a significant challenge for beekeepers [43].

A. tumida is highly opportunistic, exploiting weak or stressed colonies. Adult beetles have the ability to detect and invade hives from significant distances, using olfactory cues from bee pheromones and hive volatiles [38,47]. Within the hive, they exhibit defensive strategies such as mimicry, allowing them to evade worker bee aggression. [48] Furthermore, beetles are highly mobile and resilient, making them capable of surviving for extended periods without food, particularly in cooler environments [43].

The economic impact of A. tumida infestations on beekeeping operations is severe [49]. The destruction of honeycombs results in significant losses in honey production, while the contamination of honey with beetle larvae excrement renders it unsellable [50]. Infected colonies may abscond due to stress, leading to further economic damage for beekeepers [51,52]. Additionally, the need for pest control measures, including chemical treatments, hive replacements, and increased labor for monitoring and management contributes to rising production costs [53]. In regions where *A. tumida* infestations have become widespread, such as North America and Australia, regulatory agencies have imposed quarantine measures, further affecting trade and hive movement [47]. These cumulative losses underscore the urgent need for sustainable and effective control strategies.

2.2 Current Control Strategies for *Aethina tumida*

The management of *Aethina tumida* infestations requires an integrated approach that incorporates chemical, biological, mechanical, and cultural strategies [36]. While synthetic pesticides have traditionally been the most commonly used control method, their long-term viability is increasingly being questioned due to pesticide resistance, environmental contamination, and harmful effects on honeybees. As a result, researchers and beekeepers are exploring sustainable alternatives such as biological control agents, botanical insecticides, and mechanical trapping techniques [54]. This section examines the strengths and limitations of these control strategies.

The effective management of Aethina tumida infestations requires a multifaceted approach that integrates chemical, biological, mechanical, and cultural control strategies [36]. This is because A. tumida is a highly adaptable pest capable of rapid reproduction and dispersal, making single-method control strategies insufficient [55,56]. The spread of *A. tumida* from its native sub-Saharan Africa to regions such as the United States, Australia, and Europe has necessitated regional adaptations in management techniques, as environmental conditions and honeybee behaviors differ globally [57,58].

While synthetic pesticides have historically been the primary method of control, growing concerns over pesticide resistance, environmental toxicity, and adverse effects on honeybee health have led researchers and beekeepers to seek more sustainable alternatives [59,60]. Emerging control strategies, such as biological control agents [61,62]

2.2.1 Chemical Control Methods

Synthetic pesticides have historically been the primary method for controlling *Aethina tumida*. [63,36]. These chemicals primarily target adult beetles inside the hive or larvae pupating in soil [64]. One of the most commonly used insecticides is Coumaphos, a potent organophosphate sold under the trade name CheckMite+™ [65]. This compound is applied as strips inside beehives to eliminate adult beetles. However, studies have shown that Coumaphos residues can accumulate in wax and honey, posing potential risks to honeybee health and human consumers [66,67,68]. Another widely used insecticide is Permethrin, a synthetic pyrethroid that is typically applied to soil near infested hives to kill *Aethina tumida* larvae before they pupate. Although Permethrin has proven effective, its long-term application can harm non-target soil organisms and contribute to pesticide resistance among A. tumida populations [69,70,71].

Several newer insecticides, including Fipronil and Imidacloprid, have demonstrated high efficacy against A. tumida. However, these chemicals have been banned in multiple countries due to their detrimental effects on pollinators and environmental persistence [72,73]. The overuse of synthetic pesticides has led to growing concerns about honey contamination, colony stress, environmental degradation, and resistance development, prompting researchers to explore more sustainable solutions [74,75,76,77].

2.2.2 Biological Control Strategies

Biological control offers an alternative to chemical pesticides by using natural enemies to suppress Aethina tumida populations [49,78] Entomopathogenic fungi have emerged as one of the most effective biological agents [79,80,81]. Species such as Beauveria bassiana and Metarhizium anisopliae are capable of infecting *A. tumida* adults and larvae by penetrating their exoskeleton and disrupting their physiological functions [82,83,36]. Laboratory studies have demonstrated that *B. bassiana* can reduce *A. tumida* populations by over 70%, while M. anisopliae is particularly effective when applied to soil around hives to prevent larval pupation [84,85]. However, the efficacy of these fungi is highly dependent on temperature and humidity, which can limit their field applicability, particularly in hot or dry climates [86,87,88].

In addition to fungal pathogens, entomopathogenic nematodes have been explored as a potential biological control strategy [89,90,91]. Steinernema and Heterorhabditis species are known to actively seek out and infect A. tumida pupae in soil, significantly reducing adult emergence rates [85]. Field trials have reported up to 80% suppression of SHB populations when nematodes were applied to hive surroundings [92,47]. However, nematodes are highly sensitive to environmental conditions, requiring adequate moisture levels for survival. This sensitivity presents challenges for their large-scale deployment in regions with dry or variable climates [93,94].

Several studies have also investigated the role of predatory insects in A. tumida suppression [95,84,96]. Certain ant species, including Pheidole megacephala and Solenopsis invicta, have been observed preying on *A. tumida* larvae in natural settings [97,98]. While these predators can contribute to population control, introducing them intentionally into apiaries raises concerns regarding ecological disruption and unintended consequences for other beneficial insect species [99,100,101,102].

2.2.3 Botanical Pesticides

Botanical pesticides are being increasingly explored as an alternative to chemical insecticides due to their biodegradability, low toxicity to honeybees, and reduced risk of environmental contamination [103,104,105]. One of the most promising plant-based insecticides is *Jatropha curcas* oil, which contains phorbol esters that interfere with insect development and physiological functions [106,107]. Experimental trials have shown that Jatropha curcas oil is highly effective in repelling and killing *A. tumida* larvae, making it a potential candidate for sustainable SHB control [108].

Neem oil [109,110]. Neem-based treatments act as feeding deterrents and growth inhibitors, preventing larvae from reaching maturity [59]. Essential oils derived from plants such as thyme, clove, and peppermint have been tested for their repellent activity against *A. tumida*, though their efficacy in field conditions remains inconsistent [111]. While botanical pesticides hold significant potential, further research is needed to optimize their formulations and standardize application techniques for large-scale use [112,113].

2.2.4 Mechanical and Physical Controls

Mechanical and physical control strategies offer non-toxic methods for reducing *A. tumida* populations [114,84]. One of the most widely used mechanical control methods is the bottom board trap, which is placed at hive entrances to physically capture beetles before they gain access to the colony [53,115]. Other approaches include beetle barns, which contain pesticide-laced bait to lure and eliminate beetles, and oil traps, which suffocate adult beetles that enter the traps [116]. While mechanical interventions are effective in reducing beetle numbers, they require regular monitoring and maintenance [117]. These strategies are most successful when integrated with biological or chemical methods as part of a broader pest management program [118,119].

III. FUTURE PROSPECTS IN *AETHINA TUMIDA* MANAGEMENT

The future of A. tumida management lies in technological advancements, innovative biological strategies, and strengthened policy frameworks [75,120]. Selective breeding programs are being developed to produce A. mellifera strains with enhanced hygienic behavior, making them more capable of detecting and removing beetles [121]. Genetic engineering, particularly CRISPR-based modifications, presents an opportunity to enhance resistance traits in honeybee populations, reducing susceptibility to A. tumida infestations [122].

Biotechnological innovations such as RNA interference [123,96]. Additionally, microbial symbiont manipulation is being explored to alter the gut microbiota of *A. tumida*, disrupting digestion and survival [124]. These methods offer environmentally friendly and sustainable pest control strategies.

Artificial intelligence [125]. Smart hives incorporating automated pest management mechanisms, such as robotic trapping and real-time environmental adjustments, could significantly improve pest control efficiency while minimizing human intervention. [126]

Integrated Pest Management [127]. Standardizing best practices through large-scale field trials will improve the economic feasibility and practical adoption of these approaches among beekeepers worldwide [128].

Policy and regulatory frameworks will also play a crucial role in sustainable *A. tumida* management. Implementing safer pesticide alternatives, monitoring residue levels in honey products, and enhancing international cooperation on biosecurity measures will be necessary to prevent further spread [129]. Collaborative efforts between researchers, beekeepers, and regulatory agencies will be key to ensuring sustainable and effective control measures.

IV. DISCUSSION

While chemical insecticides remain the dominant method for *Aethina tumida* control, their drawbacks—including pesticide resistance, honey contamination, and non-target toxicity—have driven the search for alternative solutions. Biological control strategies, such as fungal pathogens and nematodes, have shown significant potential but require further optimization to overcome environmental limitations. Botanical pesticides, particularly *Jatropha curcas* and neem oil, provide a natural and eco-friendly approach but still lack standardized field application protocols. Mechanical trapping methods, while effective in reducing beetle populations, require frequent monitoring and integration with other control measures for long-term efficacy. Given these challenges, Integrated Pest Management (IPM) is increasingly viewed as the most sustainable approach, as it combines multiple control strategies to achieve effective, long-term suppression of *A. tumida* populations.

V. CONCLUSION

The threat posed by the small hive beetle on honey bee colonies cannot be over emphasized. Although chemical insecticides remain the most widely used control method, their associated risks highlight the need for more sustainable alternatives. Biological control agents, including fungi and nematodes, offer promising eco-friendly solutions but require further research to optimize their field effectiveness. Botanical pesticides, particularly *Jatropha curcas* and neem oil, present a natural alternative, though issues regarding dosage optimization and application consistency remain. Mechanical control methods provide immediate population reduction, but their success is enhanced when used in combination with other strategies.

Future research should focus on improving biological control formulations, field trials for botanical pesticides, and regulatory frameworks to support sustainable beekeeping practices. By adopting Integrated Pest Management (IPM) approaches and increasing beekeeper education, Aethina tumida infestations can be effectively mitigated while ensuring honeybee health, agricultural productivity, and biodiversity conservation.

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